

On Prediction of EOP

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Abstract

Two methods of prediction of the Pole coordinates and TAI-UTC were tested – extrapolation of the deterministic components and ARIMA. It was found that each of these methods is most effective for certain length of prognosis. For short-time prediction ARIMA algorithm yields more accurate prognosis, and for long-time one extrapolation is preferable. So, the combined algorithm is being used in practice of IAA EOP Service. The accuracy of prognosis is close to accuracy of IERS algorithms. For prediction of nutation the program *KSV_1996_1* by T. Herring is being used.

1 Introduction

Organizing the IAA EOP Service we faced the problem of development practical technique of predicting EOP, necessary to solve some problems of coordinate and time maintenance. In the present work results of the first stage of this work are presented.

The methods of predicting EOP are being advanced during long-duration time by many authors. General idea of all methods consists in determination of the statistical characteristics of an EOP series for period immediately previous to an interval of prediction and extrapolation of the found statistical characteristics in future. The methods of prediction may be separated into two groups:

- *Deterministic methods*, at application of which an EOP series is being modelled by a set of trends, garmonics, polynomials or more complex components [12, 3, 8, 9, 13].
- *Stochastic methods*, which are based on application of such models as ARIMA, Least Square Collocation and other [1, 2, 4, 5, 6, 7, 8, 10, 11, 14]. As a rule, the stochastic modeling is being applied not to initial EOP series but to residuals after exception of some deterministic components.

Unfortunately, direct comparison of various methods of predicting EOP and, accordingly, choice of algorithm the most suitable for practice using only published results is practically impossible because authors usually use different methods of testing and different EOP series to assess accuracy. Besides the practical algorithm must meet the requirement of non-interactive use and it should be also validated.

So, we undertaken some work on uniform testing of various algorithms of prediction. The technique developed with this purpose provides an assessment of prediction accuracy based on three criteria:

- root mean square residuals predicted of observed values of EOP;
- maximum residual predicted of observed values of EOP;
- influence of possible errors of last observed EOP on the result of prediction (it is important for real practice of EOP service when accuracy of last operative determinations is usually lower than accuracy of more "old" data).

The series EOP(IERS)C04 was used for testing on an interval 1990-1995 and on more short subintervals.

All told above is concerned to prediction of Pole coordinates and universal time. As for prediction of nutation, the modern models can provide high accuracy prognosis for long time intervals.

At the first stage of our work extrapolation of deterministic components, consisting of set of polynomial trend and garmonics, and ARIMA method were tested. The resulting algorithms, described below, are being routinely used in IAA beginning from June 1996. As software realizing other methods of EOP prediction is available their testing will be performed and routine technique will be corrected if necessary.

2 Prediction of the Pole coordinates

The first method of predicting Pole motion tested in IAA was the extrapolation of simple model consisting from trend, Chandler, annual, and semiannual garmonics. The base interval used for determination of parameters of trend and garmonics was varied from 1 to 6 years. The degree of polynomial trend was varied from 1 to 3. It was found that the best result can be obtained using linear trend with 1000 days base interval. To make the first predicted point agree with the last observed one the method similar to NEOS method [9] is being used except that weight parameter 180 days was found more adequate than 190 days used in NEOS practice.

Further investigations had showed that there is certain problem at the bound between observed and predicted series because of the resulting curve inflects at the first points of predictions. It can disturb the procedure of interpolation of EOP if method like spline is used. Besides it was found that ARIMA method provides more accurate result for short-time prediction. Various combination of parameters of autoregression and moving average was tested and optimal strategy was adopted. It should be mentioned that ARIMA procedure is being applied to the residuals after removing linear trend and three garmonics mentioned above. The base interval equal to 1000 days was found to be most adequate for fitting of deterministic part in this case, too. For realization of ARIMA method some routines of V. Choli was used. To get the best accuracy the correction of ARIMA parameters is being made using maximum likelihood method [1].

So, the combining algorithm was accepted as final at the moment. The interval of prediction is being divided into three part:

- for interval up to 30 days the ARIMA(1,5) method is being used;
- for interval 30–90 days the ARIMA(1,2) method is being used;
- for interval greater than 90 days the extrapolation is being used.

Since we use three various algorithm for different length of prognosis we need some procedure to join three series of predicted coordinates to one series without jumps and inflections as good as possible. This procedure consists of two step:

- the linear trend is being added to each following prognosis to bring its first point into agreement with the last point of previous one saving the last point of following prognosis as computed;
- the predicted value for bound point between two prognosis is being replaced by average of three values: last but one of previous prognosis, bound point and the second point of

following prognosis, to make the boundary more smooth.

The rms differences between predicted and observed EOPs at the interval 1990–1995 (with 10 days step) and its subintervals are presented in the Table 1 (in mas). The maximum differences (absolute values) between predicted and observed EOPs are presented in the Table 2. We considered last values as guaranteed accuracy of prediction.

Table 1: Rms differences between predicted and observed Pole coordinates.

	Days in future								
	10	20	30	40	60	90	120	150	180
1990–1995									
X_P	3.9	7.0	9.4	11.3	14.5	17.9	18.5	18.2	18.0
Y_P	3.0	5.8	8.6	11.2	15.8	20.8	24.7	26.7	27.6
1992–1995									
X_P	3.8	6.7	9.0	10.7	13.6	16.7	17.2	17.4	17.7
Y_P	2.8	5.3	7.7	9.9	13.7	18.2	22.9	26.6	29.0
1994–1995									
X_P	3.9	6.8	8.9	10.3	13.0	16.3	16.5	16.9	18.0
Y_P	2.9	5.6	8.2	10.5	14.8	19.3	25.9	31.0	34.3

Table 2: Maximum errors of predicted Pole coordinates.

	Days in future								
	10	20	30	40	60	90	120	150	180
1990–1995									
X_P	13.6	22.0	30.6	37.7	42.0	44.7	43.9	39.9	38.5
Y_P	10.0	17.5	26.7	32.1	41.8	53.2	59.6	56.0	62.0
1992–1995									
X_P	13.6	19.0	30.6	37.7	42.0	44.2	43.9	39.9	38.5
Y_P	8.0	12.7	18.8	24.1	29.9	39.9	45.6	56.0	62.0
1994–1995									
X_P	14.8	18.6	23.5	26.2	28.8	37.0	44.1	35.8	31.5
Y_P	8.1	11.6	16.6	21.7	29.8	36.4	46.1	56.2	62.4

Table 3: Influence of errors of the last values on prediction results.

Test	Days in future							
	1	3	5	10	20	30	60	90
1	2.6	5.9	7.1	6.8	6.2	4.2	2.3	1.9
2	1.2	2.2	2.2	2.1	1.9	1.7	1.4	1.2

The last test had been performed to evaluate how does prediction result react on errors of last observed values. Two kind of artificial errors was applied to real observed points:

Test 1: the value of 1 mas was added to (or subtract from) the EOPC04 value corresponding to the last observed epoch;

Test 2: the values of 0.5, 1.0, 1.5 mas were added to (or subtract from) the EOPC04 value corresponding to the three last observed epoch;

The test was used only for ARIMA method because its influence on the extrapolation of trend-garmonics model can be easily foreseen without special calculations. Corrections were applied to initial Pole coordinates on the various places of Pole motion curve. The results were very similar and typical differences between predictions of real and distorted EOPC04 series are presented in the Table 3. The table contains the result of positive correction. For negative ones the values in the table will be negative, too.

So, one can see that serious degradation of accuracy may occur when ARIMA method is used for erroneous observed EOP values. It should be mentioned that this effect practically linearly depends on the value of error.

3 Prediction of the UT1

The similar tests to ones performed for predicting Pole coordinates were made for TAI-UT1. It was found that autoregression method of order 10 is most accurate for short-time prediction (up to 15 days) and method used in NEOS [9] yields the best result for more long-time one. Before applying ARIMA algorithm the linear trend, annual and semiannual harmonics, and tidal variations are being removed from initial series. Before applying NEOS extrapolation algorithm the quadric trend, annual and semiannual harmonics, and tidal variations are being removed from initial series. Base interval used to obtain parameters of trend and harmonics is equal to 1500 days in both cases. Combining of two prognosis is being made as described above for Pole coordinates.

The rms differences between predicted and observed values at the interval 1990–1995 (with 10 days step) and its subintervals are presented in the Table 4 (in 0.001 sec). The maximum differences (absolute values) between predicted and observed values are presented in the Table 5.

Authors of [9] recommended to use smoothing of initial data before extrapolation with "moving degree" of smoothing. We could not find any significant improvement when using this recommendation. Possibly, supplement tests are needed to test such possibility of improvement of prognosis.

Many attempts was made also to improve the prediction algorithm allowing for empirically found harmonics, but without definite success.

4 Prediction of nutation

The appropriate model is apparently the best way to forecast the nutation angles. Now we use for prediction the model of T. Herring realized in his program *KSV_1996_1*. To test the program we compared the differences between this model and IAU80 theory of nutation with EOP(IERS)C04 series. The comparison showed that the bias exist between Herring's model and IERS values

$$d\psi(Herring) - d\psi(IERS) = 42.61 \text{ mas}$$

$$d\varepsilon(Herring) - d\varepsilon(IERS) = 4.95 \text{ mas}$$

Table 4: Rms differences between predicted and observed TAI-UT1.

Days in future								
10	20	30	40	60	90	120	150	180
1990–1995								
0.9	2.6	4.3	6.0	9.2	13.5	17.7	22.7	28.7
1992–1995								
0.9	2.6	4.3	5.9	8.7	12.9	17.3	23.2	30.1
1994–1995								
0.7	2.3	4.3	6.0	8.3	10.9	14.6	21.5	30.0

Table 5: Maximum errors of predicted TAI-UT1.

Days in future								
10	20	30	40	60	90	120	150	180
1990–1995								
2.6	9.0	15.0	17.2	22.2	29.8	39.3	48.7	58.8
1992–1995								
2.6	6.2	11.1	14.1	20.0	29.8	39.3	48.7	58.8
1994–1995								
1.9	5.4	10.8	13.8	20.0	27.4	40.3	49.1	58.2

for interval MJD=46000–50100 without substantial slope. After allowing for the bias the rms differences between KSV_1996_1 and EOP(IERS)C04 are equal to 0.59 mas for $d\psi$ and 0.27 mas for $d\varepsilon$. So, Herring’s model can be successively used for prediction of nutation.

5 Conclusion

The two methods of predicting EOP have been tested – extrapolation of trend-garmonics model and ARIMA. To get the best result of prognosis the combining method is being used for routine processing in the IAA EOP Service. The accuracy of prediction is close to one of IERS algorithms. So, we can hardly expect the real improvement of prediction with this class of models. Some authors propose the new stochastic [4, 7, 10, 11] and deterministic [12] methods and promise the significantly better accuracy than existing algorithms can provide. But to assess their quality it would be very important to compare them with methods routinely used now using uniform testing procedure.

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